A LABORATORY COURSE IN PHYSIOLOGICAL PSYCHOLOGY.

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Sixth Paper.

MONOCULAR PERCEPTION OF SPACE.[1]

170. The Retinal Image and Perception of Size. Accuracy of Discrimination.

The perception of size is commonly complicated with that of distance. When, however, objects are at the same distance, their apparent size will depend on the relative size of their retinal images, if the eye is at rest, or on that and the extent of the angles through which the eye must be moved to sweep over them, if it is in motion.[2]

a. Accuracy of Comparison with the Eyes at Rest. Test with Galton's bar and the krypteon[3] as follows : Place upon the middle of the flap of the instrument a small point to serve as a fixation point, and a guide mark on the back board to help in placing the bar so that its division thread may be each time exactly behind the mark on the flap. Adjust the Galton bar so that its division thread is in the middle. Place it in the krypteon and cover it with the flap. Let the subject fixate the point on the flap, and when he is quite ready let him quickly turn down the flap, and, keeping his eyes unmoved, make his judgment as to the equality of the two parts of the bar. If the parts seem unequal a constant error in his judgment is probable. Record the judgment, remove the bar and alter the setting slightly. Replace the bar as before, with the division thread behind the fixation mark, and require a new judgment. Repeat this process, gradually increasing the displacement until the subject is just able to recognize a difference in the parts of the bar. Record the difference of length required for this judgment and continue the experiment, beginning this time, however, with the parts quite distinctly unequal and working gradually toward equality.

A number of determinations should be made when the thread is displaced toward the right and toward the left and with changes towards equality and away from it—an equal number of each kind—and the average of all taken. The ratio of the just observable difference to the length of one part of the bar is the measure of the accuracy of discrimination required. Averaging the results separately for the cases in which the thread was displaced towards the right and towards the left, will show the constant error in judgment if there is any. It might seem profit-

[1]Continued from Vol. VI, 593-616, to which the reader is referred for introductory matter.

[2] The size of the retinal image is found, as explained in Ex. 112, JOURNAL, IV, 484, by drawing lines from the extreme points of the object through the Crossing Point of the Lines of Direction and prolonging them to the retina. The angle made by these lines is often called the *Visual Angle.* This construction, however, is exact only when the eye is exactly accommodated. When the eyes are not accommodated, the Sighting Lines form the angle instead of the Lines of Direction. And when objects are seen by sweeping the eye over them from end to end, the lines which give the true Visual Angle are obviously those from the extremities of the object to the centre of rotation of the eye. These various kinds of Visual Angles differ but slightly among themselves, and as a matter of fact are all purely artificial. Immediate perception knows nothing of Visual Angles, or for that matter of retinal images, but only of things seen.

[3]For description of these instruments see section on apparatus at the close of the article.

able to furnish the subject with a head-rest in order to secure a constant distance between his eyes and the bar, but there is reason to think this relatively unimportant (v. Kries, p. 187), and at all events it is not necessary for casual testing. The movements of the eyes from end to end of the bar are more important, but with care on the part of the subject, there should be no difficulty in keeping the eyes from serious movement. Of course any trials in which such occur should be reported and excluded from the record. If more perfect exclusion of eye-movements is desired, it may be obtained by placing the bar in a dark box and using flash illumination.

b. Repeat the experiment with all conditions as in *a*, except that after the showing of the bar the subject be allowed to move his eyes freely in comparing the parts. Compare the results found in *a* and *b*.

Wundt, *A*, 3te Aufl., II, 116 ff., 4te Aufl., II, 132 ff.; Helmholtz, 682 ff.; F. 695 ff. (541 ff.); Münsterberg; and the literature cited by them. For measurements of a similar kind made upon squares see Warren and Shaw (p. 240); for such measurements on circles and effect of color on size, see Quantz.[1]

171. The Retinal Image and the Perception of Size: Ordinary Seeing. In the absence of other determining circumstances, large retinal images are taken to belong to large objects and small to small. Undetermined cases are, however, extremely rare.

a. Known objects are generally Perceived as of a Constant Size Irrespective of the Size of their Retinal Images. Hold the hand eight inches from the face and notice its size; then move it to sixteen inches and observe that its apparent size remains the same, despite the fact that its retinal image has now only one-half its former length and only one-quarter its area. On further removal to twenty-four inches, the apparent size is still the same. This constancy is found in estimating the height of men, domestic animals, and familiar objects generally. This fact is frequently made use of by painters, who introduce the figures of men and other well-known objects to suggest indirectly the size of objects near which they are placed.

In somewhat the same way a well-known tower or tree may serve as a measure for the disk of the sun or moon rising behind it, with the result that these seem larger than when such comparison is impossible. This, however, is by no means the only element in the illusion. The flattened form of the sky—itself the resultant of several causes—also coöperates in making the sun or moon at the horizon seem further away and therefore larger. The matter may be followed further in Helmholtz; Wundt, *A*; Filehne; and in a discussion by Lechalas and others in the *Revue Philosophique*, Juillet, 1888—Février, 1889.

b. When the objects are equally familiar, an important part is played by attention in determining which shall be taken as the measure of the other. This is easily shown with two fingers, one held at eight, the other at twenty-four inches. Steady looking at the farther finger makes the nearer look larger than normal, and staring at the nearer makes the farther look smaller.

c. Another experiment which shows the same independence of the retinal image is cited by Helmholtz from Smith's "Opticks" (published 1738). Place in the focus of a convex lens a wafer, a printed letter or any other small object, and view it at different distances from the lens. As the distance increases, the object will seem to enlarge until it fills the lens completely. The fact is, however, that its image remains approximately constant in size (since the rays from it are made parallel by the lens), while

[1]For full titles see Bibliography at the end of the article.

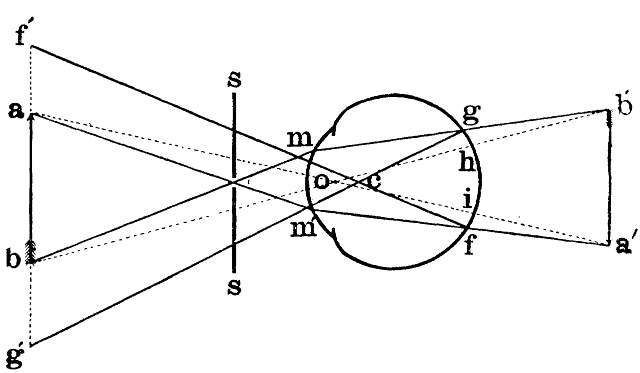
the image of the lens itself and of all other objects in the visual field decreases in size. For experiments on the exactness with which extents can be compared when their distance from the eye is unequal and when their visual angles both for the eye at rest and in motion are thus unequal, see Fechner, II, 312 f.; Martius; v. Kries, 187 ff.

Hering, 14 f.; Helmholtz, 839, F. 871 (689).

172. The Retinal Image and Perceptions of Size and Distance. A circumstance that very frequently determines the apparent size of an object is its apparent distance; or, more generally, size and distance are mutually determining. If the apparent distance is constant, the apparent size of the object changes directly with the size of the retinal image; while if the apparent size is constant the apparent distance changes inversely with the image. These are facts of very common observation. In the laboratory they may be demonstrated as follows. Look at a portion of a page of print through an ordinary magnifying glass, holding the glass near the page so that a good deal of the latter can be seen outside the lens. The retinal image of the part seen through the lens is enlarged, but the parts of the page seen outside the lens fix the distance for the whole, so that the letters seem enlarged. On the contrary, when an opera glass or a telescope is used for a distant object, the eye is brought so close to the eye-piece that nearly all the visual field, except that seen through the instrument, is cut off. The result is, then, that objects appear nearer, and but little if any larger. The effect is equally clear when the retinal images are reduced by using a double concave lens in the first case and by looking through the opera glasses from the big end in the second. See also an experiment of Hillebrand's, p. 121 f.

a. Some interesting changes in the size of the retinal image may be produced with a pierced card. Look through a fine pin-hole in a card, held as close as possible to the eye, at a printed page held an inch or two further away. The type will seem much magnified, larger even than the blurred image of it seen when the card is removed entirely. Cf. the enlarged shadow in Le Cat's Experiment (Ex. 156; JOURNAL, VI, 594). When the card is gradually moved farther from the eye and nearer the paper, the print seems still larger. A strong light on the page increases the ease of the experiment.

The understanding of this phenomenon will be assisted by the following diagram from Helmholtz:



In the usual condition of vision, objects at a distance of one or two inches appear much blurred, because the eye cannot be accommodated for them; the retinal image is made up of overlapping diffusion circles, which depend in part for their size on the size of the pupil. In the diagram the lines *ai* and *bh*, drawn through the crossing point of sighting lines *o*, touch the retina at the centres of the two circles, of diffusion representing the tips of the arrow *ab*. The intermediate points of the arrow are of course represented by circles whose centres lie between *h* and *i*. When an object is thus seen in diffusion circles, it is not taken to be of a size corresponding to the full extent of the circles, but only to the central portion of the blur. The apparent extent of the arrow as seen without the card would therefore correspond to a retinal extent not much exceeding *hi*. The introduction of the card (*SS*) with its minute opening, reduces the diffusion circles till they are hardly visible, and the blur is cleared up. The little cone of rays passing through the pin-hole from *a* reaches the eye at *m'*, and is refracted by the cornea and lens and strikes the retina at *f*. In the same way that from *b* goes to *m* and is refracted to *g*, the intermediate points of the arrow being represented as before, on intermediate retinal points. It is evident that with the pierced card the retinal surface illuminated is larger than without it ($fg > hi$), and when the image is referred outward, as usual, along the lines of direction (see Exs. 101 and 112, JOURNAL, IV, 478, 484), here *ff'* and *gg'*, the ends of the arrow will seem to lie at *f'* and *g'*, and the whole will appear enlarged. It is clear also that moving the pierced card toward the object must increase the separation of the points *m'* and *m*, and consequently of *f* and *g*. Cf. also Ex. 173.

Helmholtz, 118 f.; F. 126 f. (96 f.).

173. Perception of Depth by Means of Accommodation. Changes in accommodation produce changes in the retinal image, which certainly influence the perception of distance. Whether the direct muscular effort of accommodation has any such effect, apart from changes of the retinal image, has been questioned. Experiments have been made on the matter by Wundt (*A*, 3te Aufl., II, 92 f., 4te Aufl., II, 107; *B*, 105 ff.), by Hillebrand and by Dixon. The differences of accommodation that are required for securing sharp images of objects at the same distance, but differently colored (due to the chromatic aberration of the eye), have been held to have an effect on the apparent distance of colored objects. Experiments on this point have been made by Silvanus P. Thompson, but his results are hard to verify. The whole problem, indeed, both as to judgments depending on normal accommodation and on that required by chromatic aberration, is still *sub judice*, and will not be followed further here.

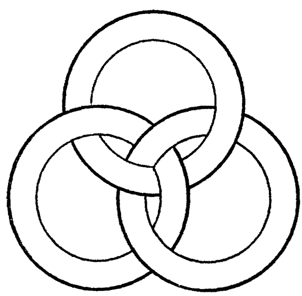
The indirect effects of accommodation have long been known, but apparently little studied. If, while attention is given to a distant object, *e. g.*, a house or tree, the eye is suddenly accommodated for a near point, the distant object will appear to withdraw and diminish in size. If the operator is not able to accommodate voluntarily, the experiment may easily be made by letting him stand close to the window and select a spot on the glass for a point of near fixation. A slight variation of the experiment with the pierced card just discussed (Ex. 172 *b*) shows the same result, heightened, perhaps, by other coöperating causes. Repeat Ex. 172 *b*, this time looking at a distant object. Accommodating for near vision now makes the object appear smaller and further away, and carrying the card toward the object produces still further diminu-

tion in size. The effect appears to be due to an actual reduction in the size of the retinal image, and can be imitated with a suitable arrangement of lenses and screens. The apparent size of the object appears also to decrease with decrease of the aperture in the card. For other changes following accommodation, see Scheiner's Experiment, Ex. 101, JOURNAL, IV, 477.

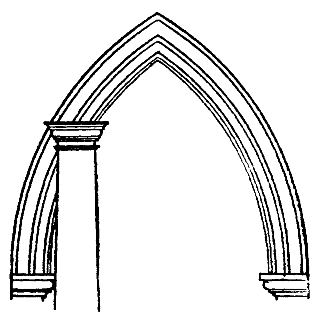
Helmholtz, 119; F. 127 (97); Walker.

174. Monocular Perception of Depth by Means of Intervening Objects.

a. Several of the monocular means of perceiving the relative distance of objects are better observed in the casual use of the eyes than in specific laboratory experiments, and this among the rest. The following figures, however, show something of the tendency. We are more inclined to regard the rings in Fig. *A* as complete and passing behind one another than as broken and carefully laid together. In the second figure the effect is still stronger, because it is still more difficult to conceive the arch in the same plane with the column and fitting exactly into its irregular contour.



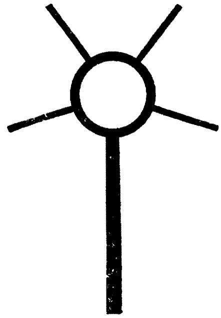
A



B

The multitude of objects intervening between the eye and the horizon, together with their known size and distances, doubtless contributes also to the flattened appearance of the dome of the sky.

b. In the following experiment the inference of intervening objects combines with the customary location of mirror-images behind the mirror surface to produce a false location of the image thrown by a concave mirror. At a distance in front of a concave mirror, somewhat less than double its focal distance, is set up a figure like that below, cut from cardboard and blackened on both sides, or even an ordinary retort ring of small size. The observer takes his position still further from the mirror in the line passing through its centre and the centre of the ring, and, if the adjustments are correct, sees floating in the air, a few inches in front of the actual figure, an enlarged and inverted image of it—so long, at least, as he observes with both eyes. The instant, however, that he looks with a single eye, the image drops back to the mirror surface or beyond. The rays of the figure and the spots on the mirror, which are seen through the floating image, and the frame of the mirror, which cuts the image off at the sides, all conspire, when the binocular means of location are wanting, to make the image seem behind instead of in front.



The dimensions of the mirror and the setting with which the writer has repeated the experiment, are as follows: Diameter of mirror, 10 cm.; Focal length, 25 cm.; Distance of the rayed figure from the mirror, 40 cm.; Inner diameter of the ring of the figure, 27 mm., outer 33 mm., length of rays, 27 mm.; Distance of the observer from the mirror, 3 m.

If the observer has difficulty in getting the binocular location, a little swaying of the head from side to side, which causes the image to shift with reference to the mirror and the figure, may be helpful.

A similar experiment may be made with suitably adjusted convex lens.

a. Helmholtz, 768, F. 793 (624); Sully, 80 f.
b. Helmholtz, 769, F. 793 (624 f.).

175. Perception of Relief by Means of Shadows.

a. The effect of shadows is finely shown by a mask colored alike within and without.[1] Place the mask, with the hollow side toward the observer, in such a position that the light falls full upon it and no shadows are cast inside it. Let the observer regard it with a single eye from a distance of six or eight yards. He will find it difficult, or even impossible, to see the mask in its true concave condition; preponderant experience apparently dictating the opposite result in perception. If, however, the position of the mask is so changed that the light falls into the mask obliquely, the shadows immediately betray the concavity, and no difficulty is found, except, perhaps, with the nose (which lies wholly in the shadow), in seeing the thing as it is.

Medallions with heads in low relief, when lighted equally from all sides, can with some effort be seen either convex or concave—cameo or intaglio. The presence of unequal illumination and cross shadows makes this more difficult. A sheet of paper folded like a half open book and set up vertically, shows somewhat the same effect, especially if the lower end is covered so that its contact with the table cannot be seen. Cf. Fig. *N*, Ex. 176 *b*.

b. Einthoven's Experiment. In the following experiment dark borders resembling shadows lead to an illusion of elevation on depression. Cut a piece of cardboard eight inches long by four wide; cover half of it smoothly with red paper and half with blue. On the red paper paste several strips of blue, and on the blue several strips of red, strips a quarter of an inch wide by two long,—or

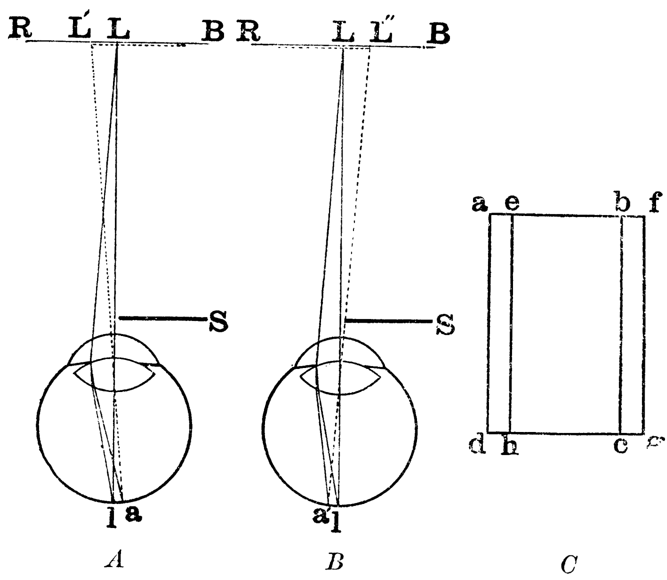
[1] This piece of apparatus originated, so far as the writer knows, with Dr. H. P. Bowditch of the Harvard Medical School.

better, put on concentric rings of the specified colors, leaving spaces between equal to the breadth of the rings. Place the diagram thus made in such a position that it shall be strongly illuminated from the right side, and view it from a distance of three or four yards with a single eye, covering half its pupil with a bit of black cardboard.

If the temporal half of the right pupil is covered, the red rings will appear to stand out slightly from their ground; the blue will appear to lie somewhat depressed in theirs. If the nasal half of the pupil is covered, the red will be depressed and the blue elevated. The same is true for the left eye if the terms nasal and temporal are interchanged. Notice in each case the apparent distribution of light and shade. Changing the direction of illumination reverses the whole phenomenon. The experiment is somewhat easier when the observer looks through a piece of blue glass (or violet or purple gelatine) held close before the eye. The edge of the card that covers the pupil may be blackened with advantage.

The purpose of the blue glass is simply to make the blue and red of the papers used in the diagram purer. In discussing the figures, it is assumed that the colors in question are perfectly pure, and that the right eye is taken for experiment, with the temporal half of the pupil covered.

The illusion depends upon the interpretation of the apparent shadows and high lights. These arise from chromatic aberration, which is made much more apparent than in the normal eye by half covering the pupil. The matter will be made clear by an examination of the figures below.



A *B* *C*

It is impossible to accommodate the eye at the same time for both red and blue; if the red rays are brought to a focus on the retina, the blue rays are focused in front of it; if the blue rays are brought to a focus on the retina, the red rays are focused behind

it. In the figures above L represents the line of demarkation between a red area and a blue area; in Fig. *A* the eye is accommodated for the red; in *B* for the blue. In *A* the edge of the red in the retinal image lies at l, the edge of the blue at a, which, when referred outward on the line of direction $a\ L'$, locates the blue edge at L', a shifting toward the left. The red edge is perceived at L in its true position. Similarly in Fig. *B* accommodation for the blue causes an apparent shifting of the location of the edge of the red to L'', a shifting toward the right. Any intermediate degree of accommodation would cause a shifting of both the red and the blue in opposite directions. In Fig. *C* is shown the result in the visual field of such shiftings. Assume that $a\ b\ c\ d$ represents a red strip on a blue ground. When this combination is viewed under the conditions of the experiment, there is a mutual shifting of the colors, so that the strip $a\ b\ c\ d$ appears in the position $e\ f\ g\ h$. The result is a summation of the colors in the region $b\ f\ g\ c$, and an absence of all color (darkness) in the area $a\ e\ h\ d$. The region of summation is taken as a high light, the region of darkness as a shadow—a condition of things that would be exactly paralleled if a slight elevation existed in a field illuminated obliquely from the right.[1]

In a way entirely similar to that just used, the cases of red figures on blue ground, of vision with the nasal half of the pupil, and of vision with the left eye, can readily be explained.

a. Helmholtz, 772; F. 798 f.; Oppel.
b. Einthoven.

176. Equivocal Figures. The last few experiments have already made clear that much of our ordinary seeing depends on an unconscious taking into account of certain elements of the general visual sensation, *e. g.*, the size of the retinal image in connection with distance, the partial covering of some objects by others and the arrangement of shadows. The nature of the percept is thus influenced by the presence of other percepts—by the perception of distance and general direction of illumination. In certain other cases the influence of these inner factors is even clearer, because voluntary changes in them bring about striking changes in the total percept. Some examples of these cases are gathered below.

a. Plane Figures. In *A* and *B* below the black and white figures are precisely alike, except in position, and either may be taken as background for the other. With the change of background, however, a sort of change of attitude is involved which is interesting. Something similar happens in *C*, which may seem a star made up of interlacing lines, two superposed triangles, or a hexagon with six little adjacent triangles. In *D* the twenty-five dots of the square may be grouped among themselves in many ways: a single square of dots; five vertical or horizontal lines; two concentric squares and a central dot; an equal armed cross filled out with four squares of four dots each, etc. A little self-observation will probably show that the change of attitude leads at once to a change of eye movements, often merely incipient, by which the new patterns are followed out.

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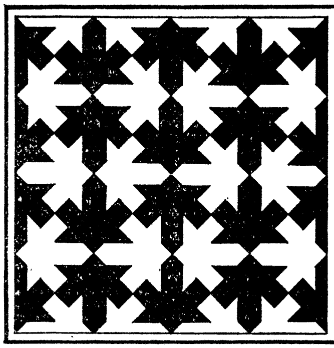
[1] It is only fair to state that Einthoven, from whom this experiment is taken, while using the apparent shadows as the basis of his explanation, rejects that given here, which depends on direction of illumination. The whole thing is a matter of perceptive interpretation, in which individual difference may well be expected, and several factors may coöperate. In repeating the experiments, however, the apparent direction of illumination has seemed to me the chief factor. Exceptions to its dominance have sometimes occurred, but for easily explicable reasons.



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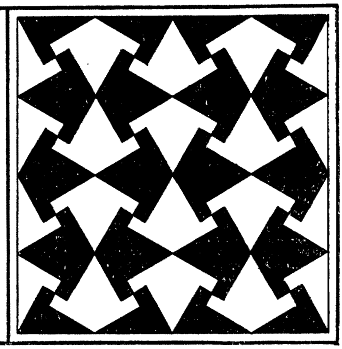

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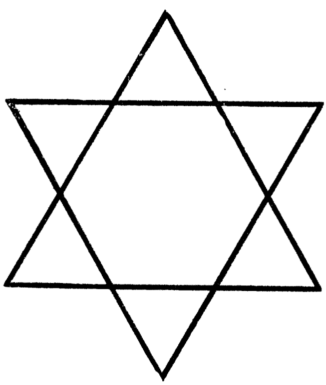

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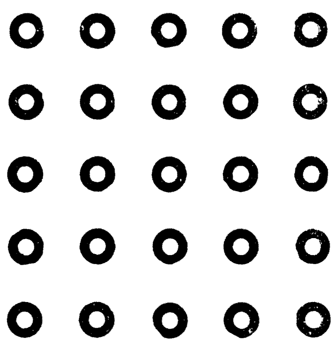
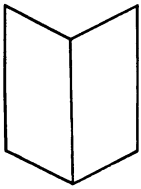


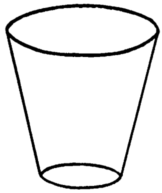
D

b. Perspective Diagrams. In the accompanying figures it is the interpretation of the space relations of the parts of the figure that change.

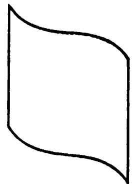
E (from Mach) represents a half-open book, and may be seen both concave and convex, the former probably being generally seen first. *F* is a glass tumbler seen from the top or from the bottom; occasionally also it may appear bent so that both top and bottom are both turned toward the observer. In *G* (from Mach) the curved lines are subject to interpretation as concave at the right and convex at the left, and *vice versa*. *H* (from Mach) is a triangular pyramid, of which the longer side is either nearest the observer or farthest from him. It also has a third interpretation, namely, as a quadrangular pyramid looked at from its apex; the diagonals of the figure then appear bent towards the paper on either side of the apex. *I* is a figure known from its originator as "Neckar's cube." Notice the change in the position of the diagonal as the cube takes one position and then the other. *J* is a set of



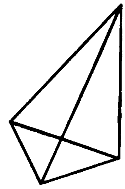
E



F



G



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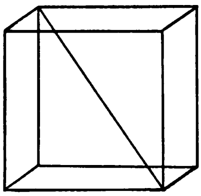

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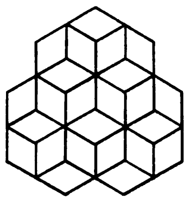
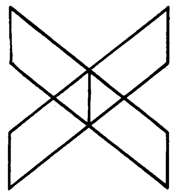
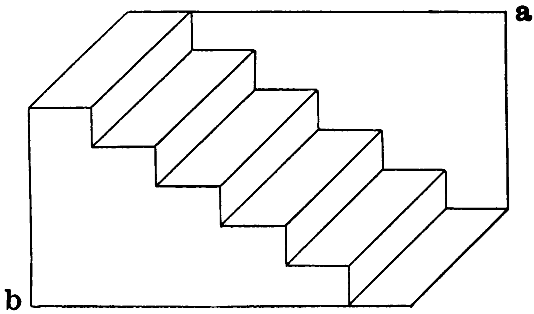


J

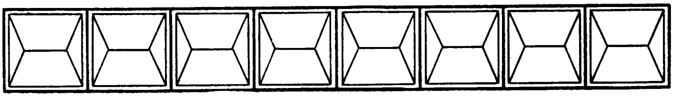


K

L



M



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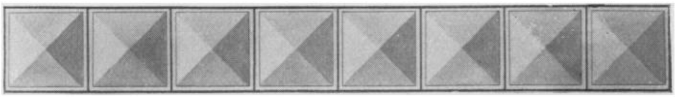


perspective cubes which appear three in the lower row, two in the middle row and one on top, or two in the lower row, three in the middle row and two on top. This figure is evidently a reduplication of Neckar's cube. *K* (from Mach) represents a pair of intersecting planes, with the line of intersection perpendicular to the paper, or lying parallel to it. *L* is "Schröder's stair figure." It generally appears first as the upper side of a flight of steps; with some effort, however, it may be seen as the under side of such a flight, or the overhanging portion of a wall. It is evidently a complication of the simple figure in *E*. *M* represents part of a narrow carved frieze from Hoppe. The little figures that compose it appear depressed or elevated. With some difficulty a part may be held as depressed while the rest are elevated, but the result is unsteady, probably because we are less accustomed to mixture of figures in such decorations than a repetition of single figures. *N* is similar to *M*, but introduces light and shade. Changes in the position of the figure with reference to the source of illumination generally involve a change from convexity to concavity, or *vice versa*. All these perspective figures have of course the intermediate interpretation of plane figures, though this is sometimes hard to hold after experimenting with the tri-dimensional interpretations. Some of the changes of form are at first a little difficult for some observers, but once gotten are easier to get again. Turning the diagram upside down is sometimes helpful. Loeb reports that moving it slowly to and from the eye causes it to change back and forth, and Mach finds these changes brought about in a slightly more elaborate figure by slow vertical movements. The Schröder figure is caused to change by vividly conceiving the plane *a* as nearer than *b*.

Notice that in all the figures changes in the position and dimensions of lines and surfaces of the figures invariably accompany their change from one interpretation to the other. In *E*, for example, when the figure is convex (the middle line nearer the observer than the rest), that line inclines, if at all, toward the observer; when the figure is concave, it inclines backward and is much larger. The relative length of the sloping lines at the top and the bottom may seem to also change slightly. It is interesting to notice that of all the possible spatial figures which could correspond to these diagrams geometrically, only a very few extremely definite ones appear to perception.

c. Three-dimensional Figures. An inversion similar to that observed in *b* can be seen with real objects when conditions are favorable. A simple experiment can be made with a visiting card bent in the middle so as to enclose an angle of about 120°, which gives a figure resembling *E* above. Set the card with the fold vertical on a table, where the light will fall parallel to one side, thus obviating the cross shadows in part (Ex. 175), and look at it from a distance of a couple of yards with a single eye. The card, like *E* above, may be seen as either concave or convex. Notice in this case, as in *b*, the changes of form and position that take place when the figure is changed from convex to concave. Notice also that when the card is seen in its illusory form (convex when it is really concave, or *vice versa*), the shadowed parts seem a deeper gray and the illuminated parts a brighter white than when the whole is correctly seen. The writer finds the experiment a little easier when the card is on a rather low table and he observes standing. The card then has the top of the table as a uniform background.

Very fine effects are to be had with casts of objects in shallow relief, either in intaglio or cameo form. In these cases the nature of

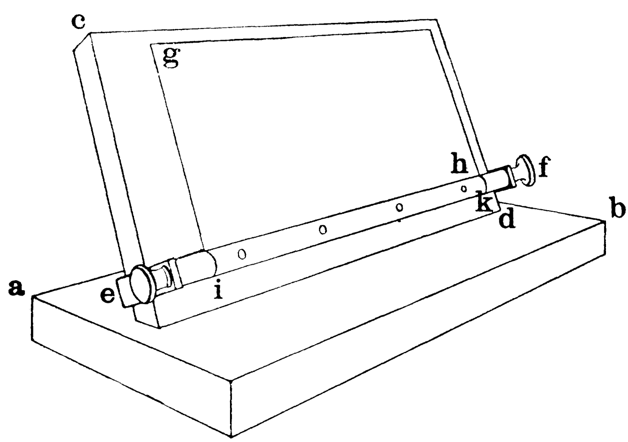
the object represented is said to be important, letters, numerals and geometrical figures turning easily either way. Natural objects, human and animal forms, and especially faces, turn easily from concave to convex, but with difficulty, if at all, from convex to concave. Compare, for example, the ease of seeing the concave mask in Ex. 175 *a* in convex form with the difficulty of getting the convex mask to appear concave.

On *a* see von Bezold, 253; Mach, *D*, 89; James, I, 442 f.
On *b* and *c*, Helmholtz, 770 f., F. 795 f. (626 f.); Wundt, *A*; 3te Aufl., II, 174, 795 ff. (626 ff.); 4te Aufl., 199 f.; Mach, *B*, 405 ff., *C*, *D*, 94 ff.; James, II, 253 ff.; Loeb: Hoppe, *A* and *B*; Brewster; Sully, 95 ff.; Beaunis, II, 569.

APPARATUS.

But little special apparatus is needed for the foregoing experiments.

KRYPTEON. The piece, which for lack of another name I have ventured to call a krypteon, is very simple in principle—nothing more, indeed, than a slanting board with a flap hinged at the bottom. Its purpose in Ex. 170 is to furnish a means of showing the Galton bar in a way that facilitates judgment without movements of the eyes. It is roughly pictured in the cut below.



On a base board *ab*, 8x20 inches in size, is set the board *cd*, 6x18 inches, inclined backward about 30° from the vertical. At the ends of this board near the base are fastened short brass arms, which extend forward and support the rod *ef*. They are of such length as to bring the middle of the rod five-eighths of an inch from the board *cd*, and seven-eighths from *ab*. The rod *ef* is provided with milled heads at the ends, so that it may be rotated easily with either hand. The rod itself is composite, being made of pieces of half-inch half-round brass, put together, flat side to flat side, to make a single round rod. The forward half of the rod is in three pieces. The middle piece *ik* is held in place by screws and can be removed; the end pieces are soldered fast to the back half of the rod. This arrangement makes it possible to clamp securely into the rod the cardboard flap *gh*, or to interchange flaps if for any reason this

is desired. When the flap is in position, the turning of the rod *ef* will rapidly cover or uncover anything placed upon the inclined surface *cd*. In using the krypteon in Ex. 170 a narrow strip of wood should be tacked along the inclined surface to support the Galton bar. The instrument is not confined in its usefulness to this single experiment, but can be used for any in which a sudden revealing or hiding of an object is desired.

GALTON BAR. This piece can be had ready-made of the Cambridge Scientific Instrument Co., St. Tibb's Row, Cambridge, England—" Line Division Testing Apparatus "—at a price of 18s. As furnished by the Cambridge company, it consists of an ebonite strip 10 inches long, 1 inch wide and 0.125 inch thick. On the back of this and extending over a little on to the face, is a light brass slider. The parts which extend over upon the front carry between them, crosswise of the bar and close to its surface, a white thread, which divides the bar into two portions—equal or unequal, according to the position of the slider. On the back of the bar a fine line is cut, which divides the bar exactly in the middle.[1] On the back of the slider there is a rectangular opening through which this line can be seen, and in the edge of the opening a scale divided to tenths of an inch, by which the displacement of the slider from the true middle can be read at once in tenths of an inch (or by estimation in hundredths), or, since the bar is ten inches long, directly in percentage of the total length. It is evidently easy to make such a bar from any rule, divided on one side only, or even with a straight slat on which a strip of millimeter paper has been pasted.

The concave mirror used in Ex. 174 *b* is to be had of any optician or physical instrument maker at small cost. The mask for Ex. 175 can be purchased at a toy store and colored within in the laboratory. Medallions for Exs. 174 *b* and 176, in plaster and about four inches in diameter are to be had in many art stores at a very low price. Casts of these in opposite relief can easily be taken in the laboratory. The other things needed—cards, pins, colored papers, convex lens and an opera glass—have either been used in previous experiments or can be found without difficulty.

BIBLIOGRAPHY.

BEAUNIS: Nouveaux Éléments de Physiologie Humaine, Paris, 1888.

VON BEZOLD: The Theory of Color, Boston, 1876.

BREWSTER: The Stereoscope, its History, Theory and Constructon, London, 1856.

DIXON: On the Relation of Accommodation and Convergence to our Sense of Depth, *Mind*, N. S. IV, 1895, 195-212.

EINTHOVEN: On the Production of Shadow and Perspective Effects by Difference of Colour, *Brain*, XVI, Pts. lxi and lxii, 1893, 191-202.

FECHNER: Elemente der Psychophysik. 2te unveränderte Auflage, Leipzig, 1889.

FILEHNE: Die Form des Himmelsgewölbes, *Pflüger's Archiv*, LIX, 1894, 279-308.

[1] There are also two other lines on the back: one at a distance from the end equal to one-third the total length of the bar; and the other at a distance from the other end equal to one-quarter the total length. These are convenient for other tests, estimating one-third or one-quarter by eye, but are not of importance for Ex. 170.

HELMHOLTZ:[1] Handbuch der physiologischen Optik, 2te Aufl., Hamburg and Leipzig, 1886–1895.

HERING: Beiträge zur Physiologie, Leipzig, 1861–64.

HILLEBRAND: Das Verhältnis von Accommodation und Konvergenz zur Tiefenlokalisation, *Zeitschrift für Psychologie*, VII, 1894, 97-151.

HOPPE: *A*, Psychologisch-physiologische Optik, Leipzig, 1881.

B, Beitrag zur Erklärung des Erheben- und Vertieft-Sehens, *Pflüger's Archiv*, XL, 1887, 523-532.

JAMES: Principles of Psychology, New York, 1890.

VON KRIES: Beiträge zur Lehre vom Augenmass, Beiträge zur Psychologie und Physiologie der Sinnesorgane (Helmholtz Festgruss), Hamburg und Leipzig, 1891, 173–193.

LANGE, N.: Beiträge zur Theorie der sinnlichen Aufmerksamkeit und der activen Apperception, *Wundt's Philos. Studien*, IV, 1888, 405 ff.

LOEB: Ueber die optische Inversion ebener Linearzeichnungen bei einäugiger Betrachtungen, *Pflüger's Archiv*, XL, 1887, 274–282.

MACH: *B*, Ueber die Wirkung der räumlichen Vertheilung des Lichtreizes auf die Netzhaut, *Sitz.-ber. d. k. Akademie d. Wiss. i. Wien, math.-nat. Classe*, LII, Abth. ii, 303–322; LIV, 1866, Abth. ii, 131–144, 393–408; LVII, 1868, Abth. ii, 11–19.

C. Beobachtungen über monoculare Stereoscopie, *ibid.*, LVIII, 1868, 731–736.

D. Beiträge zur Analyze der Empfindungen, Jena, 1886.

MARTIUS: Ueber die scheinbare Grösse der Gegenstände und ihre Beziehung zur Grösse der Netzhautbilder, *Wundt's Philos. Studien*, V, 1889, 601–617.

MÜNSTERBERG: Augenmass, *Beiträge zur experimentellen Psychologie*, Heft 2, 1889, 125–181.

OPPEL: Ueber ein Anaglyptoskop (Vorrichtung, vertiefte Formen erhaben zu sehen), *Poggendorff's Annalen*, XCIX, 1856, 466–469.

QUANTZ: The Influences of the Color of Surfaces on our Estimation of their Magnitude, *American Journal of Psychology*, VII, 1895–96, 26–41.

SULLY: Illusions, New York, 1882.

THOMPSON: On the Chromatic Aberration of the Eye in Relation to the Perception of Distance, *Phil. Mag.*, Ser. 5, IV, July-Dec., 1877, 48–60.

WALKER: On the Cause of the Different Apparent Magnitudes of the Objects seen under Different Circumstances, *Phil. Mag.*, Ser. 1, XXX, Feb.–May, 1808, 163–165.

WARREN AND SHAW: Further Experiments on Memory for Square Size, *Psy. Rev.*, II, 1895, 239–244.

WUNDT: *A*, Grundzüge der physiologischen Psychologie, 3te Aufl., Leipzig, 1887; 4te Aufl., 1893.

B. Beiträge zur Theorie der Sinneswahrnehmung, Leipzig und Heidelberg, 1862, pp. 105-134.

[1] In the references to Helmholtz the first pages given are for the second (German) edition; those following the letter F are for the French translation; those in parentheses are for the first German edition.